LIMIT EQUILIBRIUM AND FINITE ELEMENT – SHEAR STRENGTH REDUCTION STABILITY ANALYSIS, KOTA BUNYIH TAILINGS DAM, PENGKALAN HULU, PERAK, MALAYSIA

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by

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LIST OF ABBREVIATIONS

2D	two-dimensional
3D	three-dimensional
ASTM	American Society for Testing and Materials
BS	British Standard
CSS	critical slip surface
FEA	finite element analysis
FEM	finite element method
FH	falling-head
FOS	factor of safety
FOS_F	FOS with respect to force equilibrium
FOS_M	FOS with respect to moment equilibrium
GLE	General Limit Equilibrium
KB	Kota Bunyih
LEM	limit equilibrium methods
M	earthquake magnitude
MDD	maximum dry density (Mg/m^3)
MODFLOW	3D finite-difference groundwater analysis by United States Geological Survey
MP	Morgenstern and Price
MPT	modified Proctor's test
NRCS	Natural Resources Conservation Service

OMC	optimum moisture content (%)
PF	probability of failure (%)
PGA	peak ground acceleration (m/s^2)
PSD	particle size distribution
PVC	polyvinyl chloride
RF	Rossi-Forel earthquake intensity scale
RHT	Rahman Hydraulic Tin
RI	reliability index
RS2 9.0	2D finite element stress analysis program by Rocscience Inc.
SEEP/W	finite element seepage analysis by Geo-slope International Limited
Slide 7.0	2D limit equilibrium slope stability analysis program by Rocscience Inc.
SLOPE/W	Slope stability software for soil and rock slopes by Geo-slope International Limited
SPT	standard penetration test
SRF	strength reduction factor
SSR	shear strength reduction
USCS	Unified Soil Classification System
USDA	United States Department of Agriculture
USGS	United States Geological Survey
USM	Universiti Sains Malaysia

LIST OF SYMBOLS

A	resultant water forces with subscripts L and R indicates the left and right sides, respectively (N)
a	perpendicular distance from the resultant water force to the centre of rotation with subscripts L and R indicates the left and right sides, respectively (m)
a_h	horizontal ground acceleration (m/s^2)
B_s	Skempton's parameter, the ratio of change in pore water pressure over change in cell pressure in triaxial cell
c	Value of intersection between water content axis and power trend line of water content against penetration depth plot (%)
c'	effective cohesion/electrostatic forces over fine particles (kPa)
c^*	factored cohesion (kPa)
C_c	coefficient of curvature
C_u	coefficient of uniformity
D_{10}	grain size at 10% particle size distribution curve (mm)
D_{15}	grain size at 15% particle size distribution curve, the particle capture capacity of filter soil (mm)
D_{30}	grain size at 30% particle size distribution curve (mm)
D_{50}	median grain size at 50% particle size distribution curve (mm)
D_{60}	grain size at 60% particle size distribution curve (mm)
D_{85}	grain size at 85% particle size distribution curve, the erosion parameter of the protected/base soil (mm)
d	perpendicular distance of the line load to the centre of rotation (m)

E	horizontal interslice forces with subscripts L and R indicates the left and right sides, respectively (N)
e	vertical distance from the centroid of each slice to centre of rotation (m)
f	perpendicular offset of the normal force from the centre of rotation (m)
F_h	horizontal driving force (N)
$f(x)$	a function that determine the behaviour (direction) of X/E across the slope
g	gravitational acceleration (m/s^2)
G_s	specific gravity of soil
H	total head (m)
h	height of slice (m)
H_e	height of embankment (m)
h_f	distance between the overflow outlet of the basin and the final level of water on burette in falling-head test (mm)
h_L	readings of lower manometer in constant-head test (m)
H_L	localised height of slope (m)
h_o	distance between the overflow outlet of the basin and the 0 mL mark on the burette in falling-head test (mm)
h_p	pressure head (m)
H_T	total height of slope (m)
h_U	readings of upper manometer in constant-head test (m)
h_z	elevation head (m)
i	hydraulic gradient of groundwater, the subscripts x and z represent the hydraulic gradient components in x and z directions

K	seismic coefficient for horizontal force
k	hydraulic conductivity of soil (m/s). The subscripts x and z represents the hydraulic conductivities in x and z directions respectively. The subscripts 1 and 2 represent the hydraulic conductivities of soil 1 and soil 2, respectively
k_e	effective hydraulic conductivity (m/s)
k_r	relative hydraulic conductivity
k_T	hydraulic conductivity of soil at temperature T (cm/s)
k_{20}	hydraulic conductivity of soil at 20°C (cm/s)
L_L	magnitude of line load (uniform load on the surface) in force per unit width (N/m)
LL	liquid limit (%)
l	length of base of slice (m)
l_s	distance or length of soil where groundwater flow (m)
m	slope (absolute value) of power trend line of water content against penetration depth plot
ML	inorganic sandy silt
m_v	coefficient of volume of compressibility (kPa^{-1})
P	total normal force on the base of slice over a length l (N/m)
PI	plasticity index (%)
PL	plastic limit (%)
R	radius associated with mobilised shear force (m)
r	empirical (curve fitting) parameters in Van Genuchten's hydraulic conductivity model
R_T	ratio of u_T/ u_{20}

r_u	pore water pressure ratio or ratio of pore water pressure over overburden pressure
S_e	degree of effective saturation
SM	silty sand
S_m	mobilised shear strength on the base of slice (kPa)
SW-SM	well-graded sand with silt
SP	poorly graded sand
T	temperature (°C)
u	pore water pressure (kN/m^2)
U_R	pore water pressure force (N)
u_T	viscosity of water at temperature T (poise)
u_{20}	viscosity of water at 20°C (poise)
v	water flow velocity for the cross section area normal to the direction of flow (m/s). The subscripts x and z represents the water flow velocity components in the x and z directions, respectively
W	total weight of the slice of width b and height h (N)
w	weight of soil (kN)
x	horizontal distance of the slice from the centre of rotation (m)
X	vertical interslice forces with subscripts L and R indicates the left and right sides, respectively (N)
$[B]$	matrix that dependant on the nodal point coordinates
$[D]$	matrix that defines the relationship between stress and strain components (in terms of shear and bulk moduli) based on the behaviour of the soil being modelled
$[f]$	matrix of generalised displacement

$[N]$	matrix that dependant on the shapes and size of element
$[\delta]$	matrix of nodal point displacement
$[\varepsilon_e]$	matrix of strain of element
$[\sigma_e]$	matrix of stress of element
α	angle between the slice base and the horizontal (°)
α_f	initial angle of flowlines (°)
α_G	global angle of slope (°)
α_L	localised angle of slope (°)
β	deflected angle of flowlines (°)
γ_w	unit weight of water (kN/m^3)
ΔH	total head loss across the flow domain (m)
θ_Q	slope of resultant of pair of interslice forces (°)
κ_A, κ_B and κ_C	empirical (curve fitting) parameters in Fredlund and Xing's hydraulic conductivity model (kPa)
λ	a scale factor of the function
λ_p	pore size distribution index (positive)
ρ	soil density (kg/m^3)
σ'	effective stress (kN/m^2)
σ_1'	major effective principal stress (kN/m^2)
σ_3'	minor effective principal stress (kN/m^2)
τ	shear strength/stress (kPa)
φ	matric suction (kPa)
φ_b	bubbling pressure/air entry value (kPa)

$ø'$	effective friction angle of soil (°)
$ø^*$	factored friction angle (°)
ω	angle of the line load from the horizontal (°)

ANALISIS KESTABILAN SECARA KESEIMBANGAN HAD DAN UNSUR TERHINGGA – PENGURANGAN KEKUATAN RICIH DI EMPANGAN AMANG KOTA BUNYIH, PENGKALAN HULU, PERAK, MALAYSIA

ABSTRAK

Satu kajian kestabilan cerun empangan amang Kota Bunyih (KB), Pengkalan Hulu dilaksanakan bertujuan untuk menganalisis secara kualitatif kebolehpercayaan terhadap empangan amang KB dan menentukan nilai faktor keselamatan (FOS) dalam muatan keadaan resapan mantap dan keadaan seismik menggunakan Kaedah Keseimbangan Had (LEM) dan Kaedah Unsur Terhingga-Pengurangan Kekuatan Ricih (FEM SSR). Selain itu, penentuan kebarangkalian kegagalan (PF) empangan amang KB turut dilakukan menggunakan analisis kebarangkalian LEM dan FEM SSR. Analisis kualitatif terhadap reka bentuk empangan amang KB dilaksanakan berdasarkan kajian dalam pejabat, penyiasatan lapangan dan ujian makmal geoteknik. Program Slide 7.0 dan RS2 9.0 digunakan untuk menjalankan analisis berketentuan dan kebarangkalian empangan amang KB dalam pelbagai beban berdasarkan data-data geoteknikal sampel yang diperolehi. Berdasarkan analisis kualitatif, reka bentuk empangan amang KB didapati sedikit menyimpang dari reka bentuk piawai dan menyebabkan takungan air pada lokasi tertentu yang berkemungkinan meningkatkan risiko fenomena hakisan dalaman. Tambahan pula, berdasarkan taburan saiz partikel sampel tanah empangan amang KB yang diuji, didapati bahawa agregat “*New Earth Blanket*” dan “*New Dam*” tidak memenuhi kriteria ketiga reka bentuk penapis. Namun demikian, semua nilai faktor keselamatan (FOS) yang diperolehi daripada analisis resapan berkeadaan mantap berdasarkan kaedah LEM dan FEM memberikan nilai FOS>1.5 dan dikategorikan sebagai

selamat. Analisis seismik pseudo-statik FOS yang diperolehi (FOS=1.22) untuk cerun hilir didapati kurang sedikit berbanding nilai minimum 1.25 yang dicadangkan. Analisis kebarangkalian menggunakan kaedah-kaedah Spencer, Sarma dan FEM SSR memberikan nilai-nilai PF bukan sifar. Walau bagaimanapun, nilai-nilai PF yang diberikan adalah sangat kecil (< 1%) yang menunjukkan bahawa hanya segelintir permukaan gelinciran kritikal mempunyai FOS<1.5 dan tidak mempengaruhi kestabilan secara langsung. Secara keseluruhan, walaupun kestabilan cerun empangan amang KB dianggap selamat berdasarkan analisis resapan berkeadaan mantap dan kebarangkalian, kestabilan cerun empangan KB didapati kurang memuaskan berdasarkan analisis kualitatif dan seismik pseudo-statik, dan perlu diberi perhatian yang lebih pada masa akan datang.